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COSTS AND SPECIFIC IMPACTS ON MICHIGAN OF SELECTED DEICING MATERIALS

This chapter specifically identifies and, where possible, quantifies the effects of deicing materials on automobiles, highway infrastructure, and the environment of Michigan.

ECONOMIC COSTS OF DEICER CORROSION DAMAGE

There have been numerous studies estimating the various costs-direct and indirect, structural, environmental, and human-associated with the application of various deicing materials to roadways. Most, however, focus on specific sites; in this report we estimate the economic effects for all of Michigan. There are certain limitations, however. For example, in studies estimating costs for a specific area, assessments can be derived from direct observations in that locale (e.g., the number of trees and their distance from the highway, number of wells drilled to shallow aquifers, and extent of damage to all existing structures) and the associated costs estimated and totaled. In a study having the scope of this one, such direct observation is not practical. In addition, methods used to estimate costs for a small area cannot always be applied to a whole state. (In instances where such an approach can be used, however, we do so.)

A problem in estimating the cost differentials associated with various deicing materials is that while a great deal of data are available for road salt, sand, and CMA, less data are available on the others. For CMS-B and Verglimit, cost estimates could not be made at all. For CG-90 Surface Saver and calcium chloride, assumptions had to be made when specific information was not available on performance, corrosivity, and storage and equipment requirements. In instances where costs are included for some agents and not others, the discrepancy is noted and the total cost stated as unknown.

Moreover, some of the effects of deicers are not conducive to quantification. For example, their effects on the environment may be identifiable, but there is not a way to attach a practical dollar value to these effects. We know, for instance, that certain deicers can affect the life span of sensitive tree species within 30 feet of a treated surface, but it is not possible to estimate with any degree of reasonableness the number of trees in Michigan that may be so affected. Furthermore, some may argue that even if the number of trees were known, any assessment of the "cost" of tree loss would be an underestimate because of their aesthetic value, which is unmeasurable and/or subjective. In such cases-where there are identifiable but unquantifiable costs-costs have been described but no dollar value attached. Therefore, the total costs ascribed to each deicing material are understated to the extent that nonquantifiable costs are involved.

The per-ton costs of the deicers' effects are estimated and then multiplied by the number of tons of material necessary to achieve bare pavement on one e-mile of road surface. Price differentials then are compared on a cost-per-mile basis.

Direct Costs

Economic effects may be direct or indirect. For this study, direct costs are those related to the application of deicing materials:

- Procurement of various materials (price and quantity of deicer needed to carry out current MDOT winter maintenance guidelines)
- Personnel
- Corrosion (on vehicles, bridge decks, and road surfaces)
- Storage
- Equipment

Indirect costs are those that may result from one of the direct costs, i.e., road salt can corrode reinforced concrete road surfaces (a direct effect) and result in travel delays (an indirect effect) due to road repairs.

Exhibits 4.1 through 4.5 present summaries of the direct costs of using road salt, a 2: 1 salt/sand mixture, calcium magnesium acetate (CMA), CG-90 Surface Saver, and calcium chloride if all were used and applied at the current rate of road salt. (For this analysis it is necessary to consider a mixture of sand and salt, because sand alone cannot achieve bare pavement.)

It should be noted that the cost estimates are based for the most part on nationally collected data about the states; in some cases national averages are used and applied to Michigan data. Because estimates are based on aggregate figures, they cannot be disaggregated to the individual consumer level. For example, estimates of what it costs an individual for vehicle corrosion cannot be inferred; to do so would require a different estimation methodology.

Deicing Materials

To obtain the total cost of each material, the per-ton cost is multiplied by the estimated number of tons necessary to carry out the MDOT's current bare-pavement deicing maintenace guidelines. This estimate then is divided by the number of e-miles under MDOT jurisdiction to obtain the material's cost per e-mile.

Material cost estimates are based on (1) current road salt use and (2) the amount of other materials necessary to achieve the same effect. The amount of road salt assumed to be used annually is the five-year, statewide average number of tons used by contractors in counties under the jurisdiction of the MDOT. The average does not include road salt used by municipal contractors, therefore the base used for road salt cost estimates does not represent real costs. Real costs are not needed, however, because it is ***relative*** costs that are of interest. The estimates derived in exhibits 4.1–4.5 are based on cost per

Exhibit 4.1: Summary of Direct Costs of Road Salt (Sodium Chloride) as a Deicer

Procurement of materials		
Material cost		$28–30/ton
Amount needed		37 1,600 tons/year[a]
E-miles[b] treated		13,960[c]
Annual material cost		$745–799/e-mile[d]
Personnel costs		$2.642/e-mile[e]
Fixed and/or capital costs		
Storage		$0[f]
Equipment		$0[g]
Vehicle corrosion cost range		$8,550–19,020/e-mile
Estimate #1	Total	$265.5 million[h]
	Per ton	*$715*[i]
	Per e-mile	$19,020[j]
Estimate #2	Total	$1 19 million[k]
	Per ton	*$321*
	Per e-mile	*$8,550*
Bridge deck corrosion costs		
Total		$11.2-25.5 million[l]
Per ton of road salt		$30–69
Per e-mile		$804–1,827
TOTAL COST PER E-MILE		$12,741–13,818[m]

SOURCE: Public Sector Consultants, Inc., using data from the Transportation Research Board, U.S. Environmental Protection Agency, and Michigan Department of Transportation.

[a] Based on average usage over 5 years (1986-87 through 1990–9 I); includes one low-use year (198687) and one high-use year (1989-W). Twelve-year avenge is 348,500 tons. which could indicate that the 5-year figure may overstate actual material use. The number of e-miles has been increasing, however. which could account for some of the increased rate of usage during the last several years. To the extent that usage may be overstated, so are total costs, but this does not affect costs relative to other materials, because the salt use rate is the basis for estimating usage of other materials.
[b] E-mile = equivalent mile: one 2-lane mile of roadway.
[c] Three-year average.
[d] Calculation: Cost of materials x number of tons ÷ mileage.
[e] Based on 199 I costs: it must be assumed that wage, overhead, and benefits costs will increase in the future. Calculation: State avenge amount per e-mile for winter maintenance + 34 percent of average payments for benefits and overhead. The percentage is ascribed because winter maintenance accounts for 34 percent of total road costs per e-mile. less overhead and benefits.
[f] Present facilities assumed to be adequate. Road salt storage used as base line.
[g] Present equipment is assumed to be adequate. Road salt spreading equipment used as a base line.
[h] Based on 3-year average level of road salt use. Calculation: Number of registered vehicles (7.2 million, in thousands) x average vehicle price (53.684) x depreciation rate associated with road salt (1.001) x corrosion adjustment factor of deicing material in question x IO (decimal adjustment factor).
[i] Calculation: Total cost ÷ material tonnage (37 1,600).
[j] Calculation: Total cost ÷ number of e-miles treated (13,960).
[k] Based on 3-year average level of road salt use. Calculated as in estimate #1, except depreciation rate for road salt is assumed to be 0.45.
[l] Based on a 4-option range, from all damaged decks being repaired to a combination of repair and replacement (see Exhibit 4.7). Figures are based on estimates for road salt. adjusted for differences in corrosivity.
[m] Uses estimate #2 for vehicle corrosion costs.

Exhibit 4.2: Summary of Direct Costs of Road Salt-Sand Mixture as a Deicer

Procurement of materials		
Material cost		$28–30/ton road salt: $15/ton sand
Amount needed		*241,733* tons/year road salt
		123,867 tons/year sand[a]
E-miles[b] treated		13,960[c]
Annual material cost		$630–665/e-mile[d]
Personnel costs		$2,642/e-mile[e]
Fixed and/or capital costs		
Storage		$0[f]
Equipment		$0[g]
Vehicle corrosion costs range		$5,700–12,680/e-mile
Estimate #1	Total	$ 177 million[h]
	Per ton	$476[i]
	Per e-mile	$12,680[j]
Estimate #2	Total	$79.6 million[k]
	Per ton	$214
	Per e-mile	*$5,700*
Bridge deck corrosion costs		
Total		$7.5–17 million[l]
Per ton of road salt-sand mixture		$20–46
Per e-mile		$536–1,218
TOTAL COST PER E-MILE		$9,508–10,215[m]

SOURCE: Public Sector Consultants. Inc.. using data from the Transportation Research Board. U.S. Environmental Protection Agency. and Michigan Department of Transportation.

[a]Based on average usage over 5 years (1986–87 through 1990-91); Road salt-sand ratio to achieve the same effect assumed to be 2:1 (based on personal communication with the MDOT and on current use). The combined amount of salt and sand is assumed to be the same as total road salt tonnage.

[b]E-mile = equivalent mile: one 2-lane mile of roadway.

[c]Three-year average.

[d]Calculation: Cost of materials x number of tons ÷ mileage.

[e]Based on 1991 costs: it must be assumed that wage, overhead. and benefits costs will increase in the future. Calculation: State average amount per e-mile for winter maintenance + 34 percent of average payments for benefits and overhead. The percentage is ascribed because winter maintenance accounts for 34 percent of total road costs per e-mile. less overhead and benefits. Costs are divided by 2 so as to be comparable to other data. which are listed in terms of single-lane miles.

[f]Current facilities for road salt (base line) are assumed adequate: total salt and sand tonnage require same amount of storage space. but contamination containment requirements for sand are somewhat less stringent than for salt, which reduces the cost for new sand storage facilities relative to that for salt.

[g]Present equipment is assumed adequate. Road salt spreading equipment used as a base line.

[h]Calculation: Number of registered vehicles (7.2 million. in thousands) x average vehicle price ($3.684) x the depreciation rate associated with road salt (1.001) x .67 (to adjust for a smaller amount of salt used) x 10 (decimal adjustment factor). Assumes sand does not increase vehicle corrosion.

[i]Calculation: Total vehicle cost ÷ material tonnage (371,600).

[j]Calculation: Total vehicle cost ÷ average mileage (13.960).

[k]Calculated in the same manner as in estimate #1, except depreciation rate for road salt is assumed to be 0.45. Based on average vehicle price of $3.864, depreciation rate of 0.450, (adjusted for lower amount of road salt), and 3-year average level of road salt use.

[l]Based on a &option range, from all damaged decks being repaired to a combination of repair and replacement (See Exhibit 1.7). Figures are based on estimates for road salt. adjusted for differences in corrosivity.

[m]Uses estimate #2 for vehicle corrosion costs.

Exhibit 4.3: Summary of Direct Costs of CMA as a Deicer

Procurement of materials	
Material cost	$600–700/ton
Amount needed	445,920 tons/year[a]
E-miles[b] treated	13,960[c]
Annual material cost	$19,165–22,360/e-mile[d]
Personnel costs	$5,073/e-mile[e]
Fixed and/or capital costs	
Storage. total	$14.7-55.2 million[f]
Storage, per ton	$40–150
Storage, per e-mile	$1,054–3,954
Equipment	$0[g]
Vehicle corrosion costs range	$616–2,282/e-mile
Estimate #1 Total	$19.1-31.9 million[h]
Per ton	*$43-71*[i]
Per e-mile	$1,370–2,282[j]
Estimate #2 Total	$8.6–14.3 million[k]
Per ton	$19-32
Per e-mile	$616-1.026
Bridge deck corrosion costs	
Total	$1.3-3.1 million[l]
Per ton of CMA	$3.02-96.48
Per e-mile	$6.86–219.18
TOTAL COST PER E-MILE	$25,915–32,637[m]

SOURCE: Public Sector Consultants. Inc., using data from the Transportation Research Board. U.S. Environmental Protection Agency, and Michigan Department of Transportation.

[a]Based on the assumption that on average. 20 percent more CMA (by weight) is required to produce the same effect as road salt.
[b]E-mile = equivalent mile: *one* 2-lane mile of roadway.
[c]Three-year average.
[d]Calculation: Cost of materials x number of tons ÷ mileage.
[e]Assumed to be 1.92 times that for road salt; 20 percent more CMA must be applied (by weight) to achieve the same effect as road salt. CMA requires 60 percent more space by volume. requiring current equipment to be filled more frequently and make more trips. Assumes that the extra personnel requirements would be filled with additional workers; if filled by current employees working overtime, the personnel cost would need to be adjusted to account for additional compensation but less overhead and benefits.
[f]Based on the TRB estimate that CMA requires 60 percent more storage space by volume than road salt. Annual storage cost requires an additional 60 percent over the cost of storing the same tonnage of road salt. Fixed costs reflect the additional capacity required today for storing CMA (assumes current salt capacity—400,000 tons-is adequate).
[g]No additional equipment costs have been calculated. although 20 percent more CMA than road salt is necessary to achieve the same performance level, and CMA is 60 percent larger by volume than road salt. These differences are factored into personnel costs. assuming the MDOT would use existing equipment but increase the number of trips.
[h]Calculation: Numberofregistered vehicles (7.2 million, in thousands) x average vehicle price ($3,684) x depreciation rate associated with road salt (I .001) x corrosion adjustment factor for CMA (0.1 and .6, respectively, for the range provided) x IO (decimal adjustment factor) x the higher material tonnage requirement (1.2) to account for the requirement of 20 percent more CMA.
[i]Calculation: Total vehicle cost ÷ material tonnage (445.920).
[j]Calculation: Total vehicle cost ÷ average mileage (13.960)
[k]Calculated in the same manner as in estimate #1, except the depreciation rate for road salt is assumed to be 0.45.
[l]Based on a O-option range, from all damaged decks being repaired to a combination of repair and replacement (see Exhibit 4.7). Figures are based on estimates for road salt. adjusted for differences in corrosivity.
[m]Uses estimate #2 for vehicle corrosion costs.

Exhibit 4.4: Summary of Direct Costs of CG-90 Surface Saver as a Deicer

Procurement of materials		
Material cost		$185/ton
Amount needed		37 1,600 tons/year[a]
E-miles[b] treated		13,960[c]
Annual material cost		$4,925/e-mile[d]
Personnel costs		$2,642/e-mile[e]
Fixed and/or capital costs		
Storage		$0[f]
Equipment		$0[g]
Vehicle corrosion costs range		$3,925–8,730/e-mile
Estimate #I	Total	$121.9 million[h]
	Per ton	$328[i]
	Per e-mile	$8,730[j]
Estimate #2	Total	$54.8 million[k]
	Per ton	$117
	Per e-mile	$3,925
Bridge deck corrosion costs		
Total		45.2-11.2 million[l]
Per ton of CC-90		$13.86–30
Per e-mile		$369–804
TOTAL COST PER E-MILE		$11,861–12,296[m]

SOURCE: Public Sector Consultants, Inc., using data from the Transportation Research Board, U.S. Environmental Protection Agency, and Michigan Department of Transportation.

[a]Based on average road salt usage over the last 5 years (1986-87 to 1990-9 I). Assumes CC-90 Surface Saver usage is comparable to that of oad salt by both weight and volume.
[b]E-mile = equivalent mile: one 2-lane mile of roadway.
[c]Three-year average.
[d]Calculation: Cost of materials x number of tons ÷ mileage.
[e]Based on 199 I costs; it must be assumed that wage. overhead, and benefits costs will increase in the future. Calculation: State average amount per e-mile for winter maintenance + 34 percent of average payments for benefits and overhead. The percentage is ascribed because winter maintenance accounts for 34 percent of total road costs per e-mile, less overhead and benefits.
[f]Current facilities for road salt (base line) assumed to be adequate. Assumes salt and CG-90 Surface Saver are used in comparable quantities by weight and volume.
[g]Current equipment for road salt (bate line) assumed to be adequate.
[h]Calculation: Number of registered vehicles (7.2 million, in thousands) x average vehicle price ($3,684) x the depreciation rate associated with road salt (1.001) x corrosion adjustment factor for CG-90 Surface Saver (0.459, based on manufacturer's studies) x 10 (decimal adjustment factor). MDOT field studies of CG-90 Surface Saver. conducted over 9 months, revealed it to be 55 percent as corrosive as road salt. 9 percent higher than the rate found by the manufacturer.
[i]Calculation: Total vehicle cost ÷ material tonnage (37 1,600).
[j]Calculation: Total vehicle cost ÷ average mileage (13,960).
[k]Calculated in the same manner as in estimate #I. except the depreciation rate for road salt is assumed to be 0.45.
[l]Based on a 4-option range. from all damaged decks being repaired to a combination of repair and replacement (see Exhibit 4.7). Figures are based on estimates for road salt, adjusted for differences in corrosivity.
[m]Uses estimate #2 for vehicle corrosion costs.

Exhibit 4.5: Summary of Direct Costs of Calcium Chloride as a Deicer

Procurement of materials	
Material cost	$200/ton
Amount needed	371,600 tons/year[a]
E-miles[b] treated	13,960[c]
Annual material cost	$5,324/e-mile[d]
Personnel costs	$2,642/e-mile[e]
Fixed and/or capital costs	
Storage	Unknown[f]
Equipment	Unknown[g]
Vehicle corrosion costs range	$5,472–12,173/e-mile
Estimate #1 Total	$169.9 million[h]
Per ton	*$457*[i]
Per e-mile	$12,173[j]
Estimate #2 Total	$76.4 million[k]
Per ton	*$241*
Per e-mile	*$5,472*
Bridge deck corrosion costs	
Total	$7.2-16.3 million[l]
Per ton of CaCl	$1944
Per e-mile	$515–1,619
TOTAL COST PER E-MILE	$13,953–15,057 plus storage and equipment[m]

SOURCE: Public Sector Consultants. Inc.. using data from the Transportation Research Board, U.S. Environmental Protection Agency. and Michigan Department of Transportation.

[a]Based on average road salt usage over the last 5 years (198687 to 1990–91). Assumes CaCl (flake form) is comparable to that of mad salt by both weight and volume.
[b]E-mile = equivalent mile: one 2-lane mile of roadway.
[c]Three-year average.
[d]Calculation: Cost of materials x number of tons ÷ mileage.
[e]Based on 199 I costs; it must be assumed that wage. overhead, and benefits costs will increase in the future. Calculation: State average amount per e-mile for winter maintenance + 34 percent of average payments for benefits and overhead. The percentage is ascribed because winter maintenance accounts for 34 percent of total road costs per e-mile. less overhead and benefits.
[f]Using CaCl in liquid form would require new storage facilities; in pellet form, space needs would be comparable to road salt; current road salt storage facilities used as base line.
[g]Using CaCl in liquid form would require new spreading equipment. Spreading equipment necessary for CaCl in pellet form is not known.
[h]Calculation: Number of registered vehicles (7.2 million. in thousands) x average vehicle price (53.684) x the depreciation rate associated with road salt (1.001) x corrosion adjustment factor for CaCl (0.64, based on manufacturer's studies) x IO (decimal adjustment factor).
[i]Calculation: Total vehicle cost ÷ material tonnage (37 1.600).
[j]Calculation: Total vehicle cost ÷ average mileage (13,960).
[k]Calculated in the same manner as in estimate #1, except depreciation rate for road salt is assumed to be 0.45.
[l]Based on a 4-option range. from all damaged decks being repaired to a combination of repair and replacement (see Exhibit 4.7). Figures are based on estimates for road salt. adjusted for differences in corrosivity.
[m]Uses estimate #2 for vehicle corrosion costs.

e-mile and illustrate direct costs of each deicer relative to the others. The salt/sand mixture, CG-90 Surface Saver, and calcium chloride are assumed to be applied at the same rate by weight as road salt. For CMA, it is assumed-based on estimates by the Transportation Research Board'--that 20 percent more material by weight is necessary to achieve the same effect as with road salt.

A factor that can affect material and personnel costs is the longevity of deicer effectiveness. For this study it is assumed that the performance and corrosion rates of each material remain constant for equal lengths of time, although some studies indicate that the effect of CMA may carry over to subsequent storms.

Personnel

To estimate personnel costs, 1991 MDOT data for the county contractors' winter maintenance expenses per e-mile are used; to this is added 34 percent of the MDOT total for overhead and benefits (this percentage is used because winter maintenance equals 34 percent of the overall cost of road maintenance, less overhead and benefits). Personnel costs are assumed to be the same for applying all materials except CMA. Implicit in this assumption is the supposition that the necessary number of applications will be the same no matter which material is used. In the case of CMA, personnel costs are increased to account for its volume being 60 percent greater than road salt and the need to use 20 percent more of it by weight to achieve effectiveness equal to that of road salt. It is assumed that the department would accommodate the greater volume/application characteristics of CMA through personnel adjustments (increasing the number of employees and/or application trips made/ hours worked) rather than by buying new, larger-volume equipment.

Storage

The cost of storing deicing materials depends on several factors, including facility size (the number of tons it can accommodate), configuration (concrete domes versus rectangular sheds), and the amount of development required to prepare the site. Based on discussions with the MDOT, costs can range from roughly $75,000 for a 500-ton facility to $450,000 for a concrete-domed, 10,000-ton facility; this translates to a cost of $40-150 per ton for a new road salt storage facility. Among the contract counties and municipalities, the MDOT currently has storage facilities for 400,000 tons of road salt.

It is assumed that additional storage space would be necessary only in the cases of CMA and calcium chloride. To estimate the cost for CMA, the number of additional tons of material required (as compared to road salt) is multiplied by any additional volume requirements to obtain a *salt-ton equivalent storage space.* To obtain the storage cost per ton, the salt-ton equivalent storage space amount is multiplied by the cost per ton of a road salt storage facility. To obtain storage costs per e-mile, total costs are divided by the number of miles of treated roadway.

Estimates of the cost to store calcium chloride are not made; it can be manufactured in either pellet or liquid form, but there are not enough data to estimate the cost of storage for either.

Equipment and Equipment Maintenance

In estimating the costs of equipment necessary to apply the various deicing agents, it is assumed that road salt, CC-90 Surface Saver, the sand/salt mixture, and CMA would be used with existing equipment. The cost of spreading equipment for calcium chloride, in either liquid or pellet form, is not quantified in this analysis because there are insufficient data about the material's use.

It should be noted that the relative cost of switching to any deicing agent not currently in use will involve (1) a one-time fixed expenditure for modifying old equipment or buying new and (2) any increases or decreases in the cost of operating and maintaining the new or modified equipment.

Vehicle Corrosion

A number of studies on the effects of road salt estimate the costs associated with corrosion.* Arguably, the most comprehensive is a 1975 study by the Environmental Protection Agency in which motor vehicle depreciation rates are estimated for each state, using a standard linear regression model.[3] Depreciation rates are found to be a function of the amount of road salt, snowfall, and the number of miles a vehicle is driven. For this report we use as a base figure the EPA estimate of the coefficient for the effect of road salt attributable to vehicle depreciation in Michigan.

We modified the EPA depreciation rate (based on 1970 automobile prices and construction quality) to reflect the extensive anti-corrosion improvements made to vehicles since that time. The TRB cites a study by Bryant et al. in which total corrosion damage to autos is found to have declined by two-thirds (from 86 percent of all vehicles to 59 percent) from 1980 to 1985, and perforations are found to have decreased by 85 percent.[4] Using this information, we estimate the cost of corrosion on motor vehicles in two ways: Estimate #1 adjusts the depreciation rate found by the EPA down by two-thirds (from 3.003 to 1 .001); estimate #2 adjusts the depreciation rate found by the EPA down by 85 percent (from 3.003 to 0.450). Two rates are calculated because each corrosion process has a different effect on the longevity of automobiles. The two-thirds decrease is for all corrosion. The 85 percent decrease is for perforation, considered the most destructive corrosion process; this decrease results in a lower depreciation rate.

As the average vehicle price, the EPA used $1,500. To update the figure for this study, the increase in the consumer price indices from 1970 to 1990 for new and used vehicles is applied to $1,500 in proportion to the current distribution of vehicles in Michigan; the average price is found to be $3,684. To obtain the total cost of vehicle corrosion attributable to road salt, the cost figure is applied to the roughly 7.2 million registered vehicles in Michigan. The information used in obtaining this value is contained in Exhibit 4.6.

To obtain an estimate for the corrosion costs of materials other than road salt, the cost of road salt is adjusted downward based on the corrosivity rate of the other materials relative to road salt. The following are the assumed rates:

- CMA is 10 percent as corrosive as road salt[5]
- CaCl is 64 percent as corrosive as road salt[6]

Exhibit 4.6: Calculation of Average Motor Vehicle Price in Michigan

EPA price estimate (1970)	$1,500
Distribution of vehicles (1990)	
Percentage new (<3 years)	21.1%
Percentage used (3 years and older)	78.9
Percentage increase in prices (1970-90)	
New	128.0%
Used	277.0
Average vehicle price (1990)	
Contribution of new cars[a]	$405
Contribution of used cars[b]	3,279
Total	$3,684

SOURCE: Public Sector Consultants, Inc., using data from Bureau of Labor Statistics, U.S. Department of Labor. and Environmental Protection Agency.

[a]Calculation: 1970 EPA estimate for the average car price x percentage of total cars in 1990 defined as "new" x increase in new car prices rom 1970 to 1990.
[6]Calculation: 1970 EPA estimate for the avenge car price x percentage of total cars in 1990 defined as "used" x increase in used car prices from 1970 to 1990.

- CG-90 Surface Saver is 46 percent as corrosive as road salt'

The vehicle corrosion cost estimates in this study are based on the total decline in a *vehicle's value that is attributable to deicing material.* Some studies use the costs incurred for *specificallypurchased vehicle rust prevention measures;* the rationale is that the cost of corrosion equals what people are willing and able to pay for measures to prevent it. We believe, however, that if the figures derived from the purchased prevention measure methodology are used, they should be used only in addition to the *costs* derived from estimating the decline in vehicle value attributable to deicers. The fact is that vehicle depreciation rates have declined over the past few years in part because manufacturers have instituted design and material improvements to reduce corrosion. As a result, late-model cars depreciate more slowly than older models, but their owners already have involuntarily borne some of the expense; part of the price of their cars covered the design and material improvements that have slowed depreciation. Moreover, the purchased prevention measure methodology fails to take into account that not all vehicle corrosion is caused by deicing materials (some is caused by salt in the air, for example). *The corrosion cost estimates in thisstudypertain only to damagefrom deicers and only as they affect a vehicle's total value.*

If readers wish to add to our cost estimates an additional amount for purchased corrosion prevention measures, the amount per new vehicle is $ 125–250.[8] Applying this cost to the roughly 380,000 new vehicle registrations in Michigan in 199 1 yields a total annual cost of $47.5 million to $95 million for road salt (or $3,400–6,800 per e-mile); this amount can be reduced by the same methodology used in estimates #1 and #2 to find the comparable costs of the other deicing materials, but it will overstate the cost attributed to road salt because purchased corrosion prevention measures also are used to combat the corrosive effects of acid rain and natural corrosion in humid and coastal areas.

Bridge Deck Corrosion

One method for estimating the cost of deicer use on bridge decks is to compare deterioration rates of structures in Michigan to those in regions of the country where road salting is minimal or not done. (However, we assume that the difference in deterioration rates is a function only of the application of deicing materials and not of wider temperature ranges, more freeze-thaw cycles, differences in the local aggregates used in constructing bridge decks, and differences in bridge design). The age distribution of bridges in Michigan, the amount of deck area, and the costs associated with structural replacement and repair can be combined with this information to arrive at a rough estimate of the costs to structures attributable to deicing materials.

A computer analysis by the TRB of the National Bridge Inventory files finds that among the Great Lakes states, of bridge decks l-10 years old, 92 percent are in sound condition and not critically contaminated with chlorides;[9] of those aged 1 l-20 and 2 l-30 years, the figures are 80 percent and 58 percent, respectively. In the southern and western regions of the United States (where salting is negligible), of bridge decks aged 1–10, 92 percent are undamaged, the same as in the Midwest; 85 percent of those aged 1 l-20 and 76 percent of those aged 21-30 are in sound condition in the South and West, somewhat better than found in the Midwest.

The difference in deterioration rates in the Midwest versus the South and West is applied to the number of bridge decks in Michigan (according to their current age) to find the estimated number of Michigan decks that can be expected to deteriorate during the next 10 years. Exhibit 4.7 summarizes the age distribution of bridges in Michigan and the costs of the following four bridge deck repair/ replacement options:

- Repairing all bridge decks damaged over the IO-year period
- Replacing all decks affected by road salt
- Repairing all decks aged 30 years and under; replacing all more than 30 years old
- Repairing all decks up to 20 years old and half those 2 l-30 years old; replacing half the decks 21-30 years old and all those more than 30 years old

The following assumptions are used: The average deck size is 7,000 square feet, the replacement cost is $70 per square foot, the repair cost is $29 per square foot, and repairs are distributed evenly over the lo-year period.[10] Costs are attributed to deicing materials other than road salt by reducing costs associated with salt by the difference in the corrosivity rates of the other materials (as listed for vehicles in the section above).

It must be noted that the estimate for bridge deck damage could be over- or understated to the extent that Michigan average deterioration rates could be below or above Midwest rates or that corrosion occurs for reasons other than the application of deicing materials. The estimate also could be overstated to the extent that retroactive measures have slowed historical deterioration rates. Such an effect, however, most likely is negated because all Midwest deterioration rates reflect corrosion prevention measures mandated in the late 1970s for bridges built with federal matching funds.

Exhibit 4.7: Age Distribution of Bridges in Michigan, Estimates of Bridge Deterioration Rates, and Deck Repair and Replacement Option Costs During the Next Ten Years

	Age				
	1-10	11-20	21-30	>30	Total
Total number of bridges	387	556	1,474	2,074	4.491
Percent undamaged[a]	92%	80%	58%	58%	
Number undamaged	356	445	855	1,203	2,859
Percent damaged due to road salt[b]	0.0%	5.0%	18.0%	18.0%	
Number expected to deteriorate[c]	31	46	122	781	980
Number expected to deteriorate due to road salt	0	19	72	461	552
Option 1					
Cost, all decks repaired[d]	$0	$3,928,050	$14,672,840	$93,631,720	$112,232,610
Annual cost	0	392,805	1,467,284	9,363,172	11,223,261
Option 2					
Cost, all decks replaced[e]	$0	$9.481,500	$35,417,200	$226,007,600	$270,906,300
Annual cost	0	948,150	3,541,720	22.600.760	27,090,630
Option 3					
< 30 years, decks repaired		$3,928,050	$14,672,840		
> 30 years, decks replaced				$226,007,600	$244,608,490
Annual cost		392,805	1.467.284	22,600,760	24,460,849
Option 4					
1–20 years, decks repaired		$3,928,050			
21-30 years, decks repaired[f]			$7,336,420		
21-30 years, decks replaced[g]			17,708,600		
>30 years, decks replaced				$226.007.600	
Total cost					$254,980,670
Annual cost					25,498,067

SOURCE: Public Sector Consultants. Inc.. using data from Transportation Research Board and Michigan Department of Transportation.

[a] Based on Transportation Research Board analysis of National Bridge Inventory.
[b] Based on the difference between the percentage of bridges damaged in the Midwest and in regions where road salt is not used or use is minimal.
[c] Assumes that the same number of bridges will be constructed in the next 10 years as were in last 10.
[d] At $29/square foot. with average deck size of 7.000 square feet (source: MDOT).
[e] At $70/square foot, with average deck size of 7.000 square feet (source: MDOT).
[f] Half of the bridge decks are assumed to need repair only. Assumption based on these bridges having been treated with at least some corrosion prevention materials.
[g] Half of the bridge decks are assumed to need replacement. These bridges have not been treated with any corrosion prevention materials.

These estimates also do not include the costs of repairing other components of bridges, such as grid decks, joint devices, drainage systems, or structural components made of steel-reinforced concrete and prestressed concrete; therefore, the estimates do not reflect total costs of bridge corrosion attributable to road salt.

Roadway *Effects*

The economic effect of road salt on pavement has not been estimated, and thus comparisons of the effect of other materials cannot be made. Roadway damage due to salt is difficult to estimate for several reasons. The quality of construction is one factor: Surface flaking can only worsen from road salt if construction was inadequate or poor, although this effect has been greatly reduced due to improvements in standard construction policies (such as for concrete air entrainment) and is said to no longer be of major concern to highway agencies."

A second problem is pavement cracking and rupture due to corrosion of steel expansion joints. It is difficult to estimate the damage (and the costs) attributable to road salt alone. Water and other materials can cause or contribute to the corrosion of these joints. The costs of joint corrosion prevention measures, such as for epoxy resteel (which adds $. 15 per pound of steel to total costs) could be used, but they could be incurred even in the absence of using road salt.[12]

Reinforcing steel is used to strengthen pavement and eliminate the need for reinforcing joints, but it is subject to pavement cracks and fissures due to rebar corrosion. Costs for this type of problem are difficult to estimate because studies indicate that pavement deterioration in high-volume traffic areas could be the same whether or not road salt is used.

Environmental Effects

The specific circumstances under which environmental components-soils, vegetation, and surface water, for example-are affected by deicing materials are covered below under environmental impacts. Estimating the statewide costs associated with the effects on these components is not feasible because the costs are incurred in very specific areas and under very particular circumstances. Road salt, for example, might have an effect on a specific tree if it is a salt-sensitive species and adjacent to a heavily travelled roadway. Without a statewide survey of such occurrences, it is impossible to quantify their frequency.

Moreover, effects on the environment are identifiable, but attaching adollarvalue to them is complex and too subjective to be reliable. How does one attach a monetary cost to the death of invertebrates in a small stream, and how does it compare to the cost of the death of a tree beside a highway? Although the monetary costs to the environment due to the use of deicers are not quantified in this report, the importance of the effect of deicers on the environment is recognized, and vulnerable environments are identified in the last part of this chapter.

Traveler Safety

Some studies try to estimate how the costs of damage to property and individuals are affected by the use of deicers.[13] These studies, however, focus on differences in levels of *service* rather than on different types of deicing *materials*. In this study we assume the level of service already being provided by the MDOT will continue no matter what material is used, so costs relative to safety are the same for all materials. (See the introduction to this report for current MDOT winter maintenance guidelines.)

Indirect *Costs*

Traveler Productivity and Time

There are several estimates of the costs to businesses and individuals of delays resulting from untreated roadways.[14] As in the case of safety, these studies are primarily concerned with varying levels of service-wet pavement versus bare wheel paths, for example-rather than differences in deicing materials. In this report we assume the MDOT will not change maintenance guidelines, only the materials it uses to carry them out. Therefore, traveler productivity and time considerations are irrelevant to this particular study. In the case that one deicer takes greater effort to apply than another, it is assumed in this study that personnel and equipment would be increased to keep the application time constant.

Human Health

For people sensitive to sodium, the infiltration of road salt into their water supply can affect their health (see chapter 3), requiring them to alter their water consumption pattern, usually by substituting commercial bottled water for tap water. Assuming a consumption rate of one gallon of bottled water per day at an average cost of $.80–.85 per gallon, such individuals incur additional costs of approximately $290-3 10 annually. The frequency of this type of occurrence is thought to be negligible, however, as it requires the combined incidence of road salt infiltrating a private well and an individual dietary restriction. In the case of other materials, no effect on human health is expected.

Summary

Because many of the alternative deicing materials evaluated in this report are not used extensively in the United States or, more specifically, in Michigan, our quantification of direct and indirect costs to society attributable to their use can be considered only an estimate. Assumptions had to be made for each material about application rates, longevity of effectiveness, and personnel, storage, and equipment costs. Some of the corrosion rates used have not yet been tested by highway agencies or independent bodies. Other costs, such as those stemming from the effects of deicers on roadway surfaces, the environment, public safety, and public health simply cannot be quantified.

The purpose of our analysis is to estimate some of the economic costs of each deicing material, using available information. The most important aspect of this analysis is not the total costs for each deicer, but the costs of each deicer *relative* to *the others.* Our analysis shows that the salt/sand mixture, CG-90 Surface Saver, and road salt, respectively, cost society least on a total cost-per-mile basis. The total cost per mile for CMA is significantly higher than the others: approximately twice the cost of sodium chloride, 3 times the cost of the salt/sand mixture, and 2.5 times the cost of CG-90 Surface Saver. Calcium chloride cannot be compared because storage and equipment costs are not derived for it (although indications are that even without accounting for these costs, calcium chloride still is more expensive to society than are the salt/sand mixture, CG-90 Surface Saver, and salt).

ENVIRONMENTAL IMPACTS OF DEICERS

Specific concerns about the effect of road deicers on Michigan's vegetation, water bodies, aquatic biota, and human health are addressed by identifying areas susceptible to the effects of the various deicers. The information used to identify potentially vulnerable areas comes from chapter 3.

Impact of Road Salt Use on the Great lakes

To determine the effect of current road salt use on the Great Lakes, a model was developed to analyze the cumulative impact of road salt—more specifically, chloride--on the Great Lakes.

Chloride in the Great Lakes

The impact of deicers on the Great Lakes region is of particular importance in this study because of the length of Michigan's Great Lakes shoreline: 3,288 miles (including islands), more than any other state. Virtually all of Michigan's surface water drains into the Great Lakes basin. Maintaining the health of the Great Lakes ecosystem is of paramount importance to the Michigan public, who depend on the lakes for recreation and commerce as well as human and industrial water supplies.

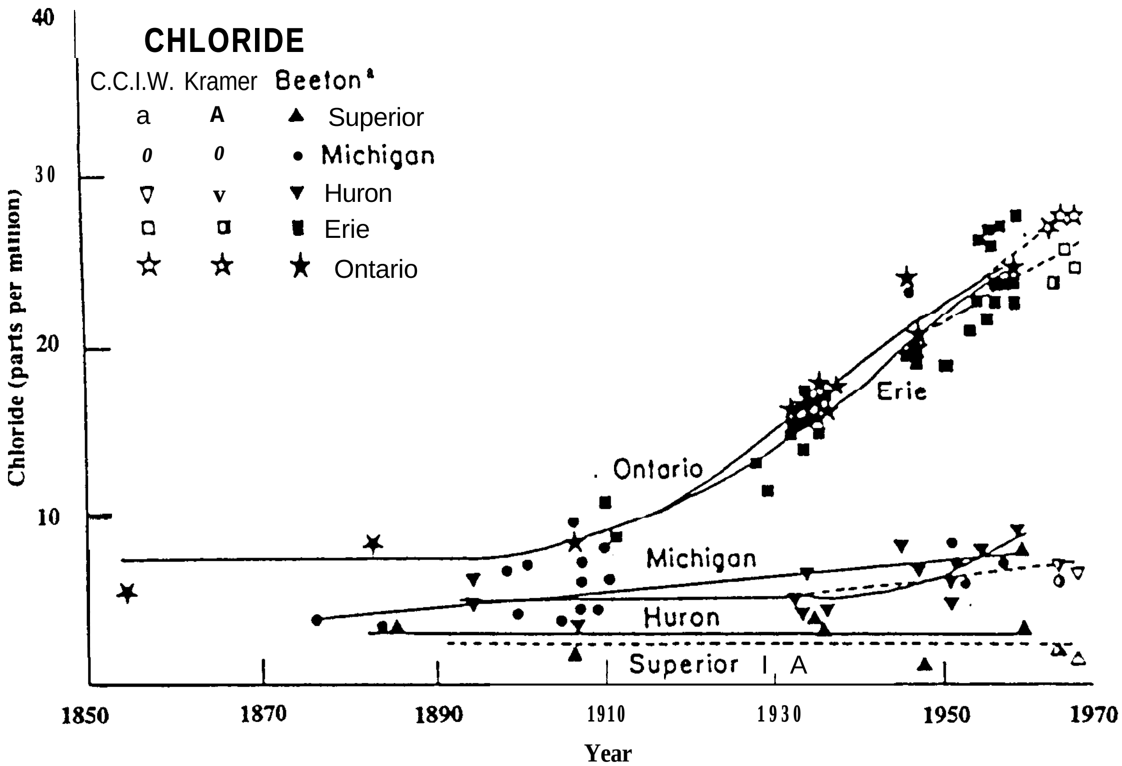
Monitoring of Great Lakes water quality has been sporadic and conducted by many different agencies and interests; this makes it difficult to develop a central database to monitor trends in pollutant levels. Historically, chloride has been the most closely monitored contaminant because it is a conservative element (that is, it does not readily change) and tends to accumulate in proportion to *loading* (input) levels. Therefore, chloride is used as an indicator of potential pollutant levels from a variety of sources such as industrial and municipal discharges, natural weathering of soil and rock material, atmospheric deposition (e.g., precipitation), and nonpoint (diffuse) runoff that includes deicing materials. Some estimates indicate that runoff from road deicing accounts for 35 percent or less of chloride loads in the Great Lake system.[15]

There is general agreement that chloride levels have increased in the Great Lakes, but each lake shows a different trend. Exhibit 4.8 shows the historical trends of chloride in the Great Lakes from 1850 to 1970.[16] In 1992 Moll and others developed water quality databases for Lake Michigan, Lake Huron, and the Saginaw Bay by bringing together monitoring data from the EPA, U.S. Fish and Wildlife Service, National Atmospheric and Oceanic Administration, Army Corps of Engineers, various state agencies, and university studies.[18] Exhibit 4.9 shows chloride concentration levels for Lake Michigan from 1962 to 1986.

Lake Michigan receives chloride from many tributaries. Chloride loadings are highest in the southern basin; in 1976, 1.5 more ppm were found in the southern part of the lake than in the northern part. Overall chloride levels in Lake Michigan increased from 3 ppm in the 1870s to approximately 8 ppm by 1980. Current chloride levels are estimated to be 8 ppm.[18]

Lake Superior has maintained the lowest chloride load of the Great Lakes-at one ppm-for the last 200 years. Chloride levels have remained this low largely because the lake receives little industrial and municipal discharge, minimal input from natural sources, and comparatively small amounts of

Exhibit 4.8: Historical Trends in Great Lakes' Chloride Concentration



SOURCE: Pringle, C.M. et al. Biological *Effects of Chloride and Sulfate wirh Special Emphasis on the Laurention Great Lakes,* University of Michigan. Great Lakes Resevch Division, AM Arbor.

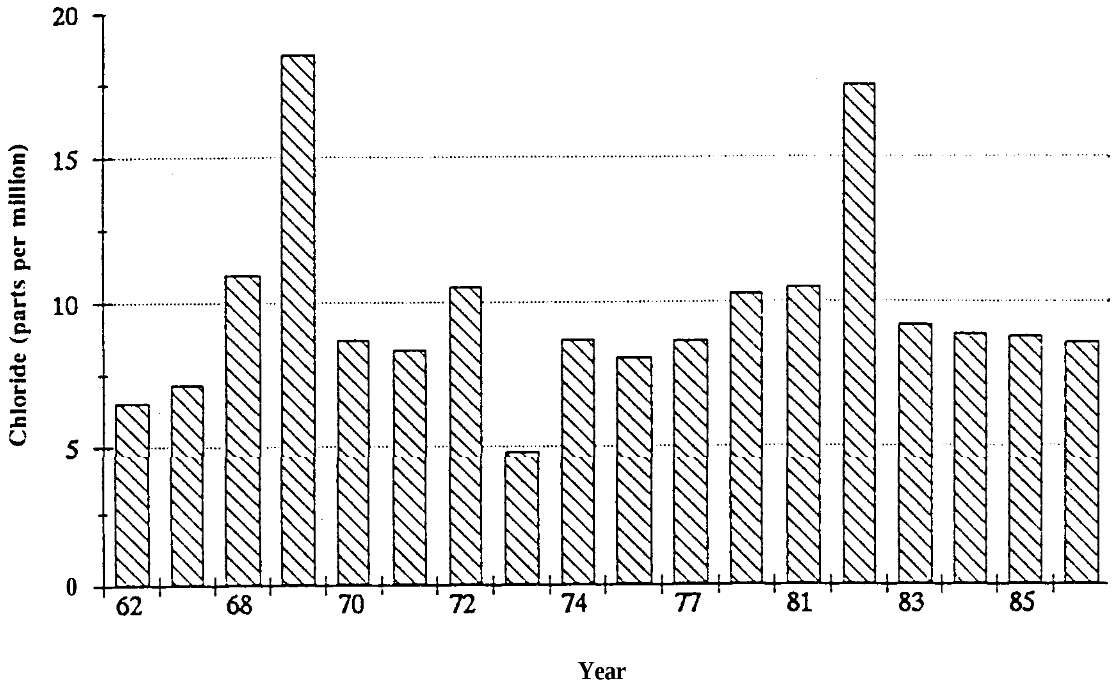
"C.C.I.W. = Canada Centre for Inland Waters. 1968, unpublished data; Kramer = Kramer, J.R.. 1964, Theoretical model for the chemical composition of fresh water with application to the Great Lakes. Proc. 7th conf. Great Lakes Res., University of Michigan, Great Lakes Resevch Division, Publication No. 11; Beeton = Beeton, *A.M.,* 1965. *Eutrophication of the St.* Lawrence *Great Lakes,* Limnol.,Oceanogr., 10240.

runoff from road deicing. In addition, the lake's large volume of water (12,230 cubic kilometers) is capable of diluting any chloride that does enter the lake.

Lake Erie has experienced considerable contamination; chloride levels rose from 10 ppm in 1910 to more than 25 ppm by the late 1960s. Lake Erie has the smallest volume of water (483 cubic kilometers) of the five lakes and receives considerable discharge from the Detroit River and other tributaries, which contribute to its high chloride concentration. Recently, levels have decreased to 20 ppm due to the remediation (correction) of industrial discharges. The effects of the remediation efforts were seen quickly because of the short turnover time of the lake (2.6 years).

Chloride levels in Lake Ontario show trends similar to Lake Erie. They increased from 10 ppm in the 1900s to 25 ppm in the late 1960s. Lake Ontario receives its primary input from the Niagara River. Despite recent remediation efforts, decreases in chloride levels have not yet been detected in Lake Ontario because its turnover time is six years.

Exhibit 4.9: Changes in Dissolved Chloride Concentrations in Lake Michigan



SOURCE: Public Sector Consultants, Inc., from information from Moll, R.A. et *al.,* 1992. ***Historical Trends of Chlorides in the Great Lakes.*** in F.M. D'Itri, ed., 1992, ***Deicing Chemicals and*** the ***Environment,*** Lewis Publishers.

The predominant sources of chloride in Lake Huron are the Saginaw Bay tributaries, which include significant agricultural, municipal, and industrial discharges. Chloride concentrations in lower Saginaw Bay rose to 60 ppm in 1956, and Lake Huron levels increased from 5 ppm in 1900 to 7 ppm by the late 1960s. Beginning in 1970 enhanced pollution control measures have significantly reduced chloride levels in Saginaw Bay (which ranged from 5-90 ppm in 1965 to 2-24 ppm in 1980).[19] Since the late 1960s Lake Huron concentrations have decreased to 5 ppm chloride.

Chloride Levels Toxic to Aquatic Biota

Current chloride concentrations in the Great Lakes do not pose a problem to the majority of the lakes' aquatic biota, which show no effects at chloride concentrations below 1,000 ppm sodium chloride.[20] Acute (one-time) levels of sodium chloride toxic to freshwater animals in Michigan range from 1,470 ppm for *Daphnia pulex* to 11,940 ppm for the American Eel. General sodium chloride levels toxic to freshwater plants in Michigan range from 220 ppm for desmid *Metrium digitus* to 24,300 ppm for alga *Anacystis nidulans*.[21]

Pringle et al. also evaluated the effects of chloride and sulfate on the Great Lakes biota and find Great Lakes chloride levels to be significantly lower than those found to be toxic to aquatic biota.[22]

Model of Impact to Great Lakes Chloride Levels from Increasing Chloride Loading Rates

For this study a model was constructed to examine potential changes in chloride concentrations in the Great Lakes when chloride loadings are increased. Information used to generate the model includes a review of historical trends in the Great Lakes, projections of future levels at current road salt usage rates, and basic information on the volume and turnover rates (the time it takes a lake to evenly distribute a change in input) of each lake. The model predicts the effect of increases in the amount of chloride entering each lake on chloride concentrations of the Great Lakes system. Also determined is the effect on each lake's own chloride level by directly increasing its chloride load without accounting for linkage effects of adjoining Great Lakes. Detailed descriptions of the model and methodology are attached as appendix C.

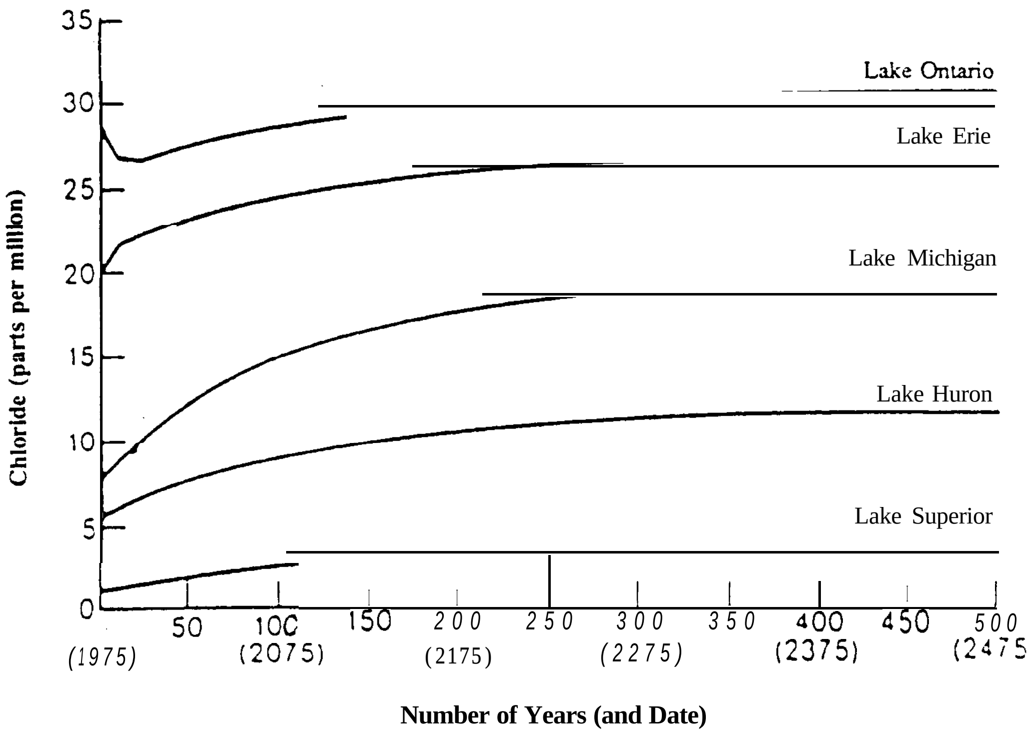
Sonzogni et al. examined chloride loading to the Great Lakes and conclude that road salt contributes to anthropogenic chloride in the Great Lakes. However, even if all chloride entering the Great Lakes watershed from road salt reaches the lakes, road salt generally accounts for less than 35 percent of the lakes' total chloride.[23] The study also concludes that the chloride input to and output of the Great Lakes is not in steady *state* (the condition when input of a chemical component equals the output of the component for a particular system). Exhibit 4.10 shows Sonzogni's projection of when steady state chloride levels will occur at current rates of chloride loading. The model begins in 1975 and steady state is approached around 2275. Chloride concentrations at steady state are 4 ppm for Lake Superior, 20 ppm for Lake Michigan, 10 ppm for Lake Huron, 25 ppm for Lake Erie, and 30 ppm for Lake Ontario.

Given Sonzogni's projections, the model determines the steady state levels of chloride concentrations in each lake when total chloride loads entering the system are increased by 1, 10, 50, 100, and 200 percent. The methodology is summarized below.

Because chloride is a conservative ion, it is assumed that when chloride enters the Great Lakes system, it remains in solution. Chloride steady state levels are a function of lake water volume, total chloride content, and turnover time. Strachan and Eisenreich's estimates of total water volume for each lake are used.“' The total volume of chloride in each lake is calculated by measuring the amount of water entering the lake-through tributaries, channels from other lakes, and rainfall--equal to the amount of water leaving the lake. Base-line concentrations of chloride in the lakes are taken from the projected estimates of Sonzogni et al. at the steady states listed above for current usage. Turnover time for each lake is calculated, assuming that chloride and water turnover times are the same. From the turnover time, the rate of change for each lake is estimated. Values used in the model for the water volume, chloride volume, and turnover time of each lake are included in Exhibit 4.11.

Using the volumes of water, mass amounts of chloride, and turnover rates for each lake, changes in chloride steady state levels for the Great Lakes system are derived for each lake. Exhibit 4.12 indicates the steady state concentrations for each lake for each percentage increase. It is important to note that these calculations are made by integrating the effects of the lakes on each other and using acombined turnover time of 200 years, meaning these levels will reach steady state for the entire Great

Exhibit 4.10: Projections of Great Lakes' Chloride Concentrations Over Time in Response to Current External Loads



SOURCE: Sonzogni et al.. 1983. "Chloride Pollution of the Great Lakes," *J. of Water Pollution Control Federation*. 55(5):5 13-521

Exhibit 4.11: Water Volume, Chloride Content, and Turnover Time for the Great Lakes

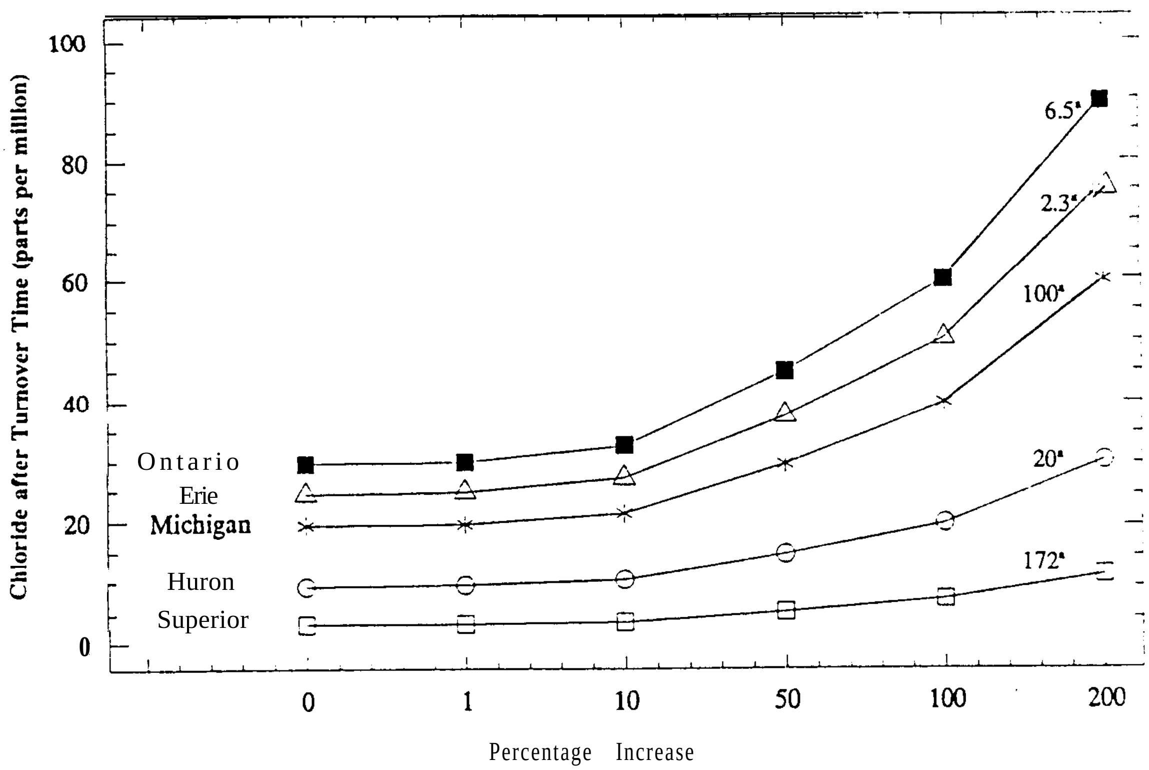
Lake	Water Volume (KM^3)[a]	Chloride Content (mg x 10^{13})[b]	Turnover Time[c] (years)
Superior	12.230	4,892	172
Michigan	4,920	9.840	100
Huron	3,537	3,537	200
Ontario	1,636	4,908	6.5
Erie	483	1,208	2.3

SOURCES: Water volume data from Strachan and Eisenreich; other data from Public Sector Consultants. Inc

[a]Cubic kilometrrs
[b]Milligrams multiplied by 10 to the 13th power
[c]Time required to adjust to changes in input.

Lakes system in 200 years. Additionally, the percentage increases represent increases in total chloride loads, not increases in road salt use (which comprises only 35 percent of chlorides reaching the lakes). For example, a 100 percent increase in chloride loading is a 570 percent increase in road salt use. As the exhibit indicates, if total chlorides reaching the lakes were doubled (100 percent increase; 570

Exhibit 4.12: Effect of Increasing System-wide Chloride Input on Great Lakes' Chloride Concentration



SOURCE: Public Sector Consultants, inc.

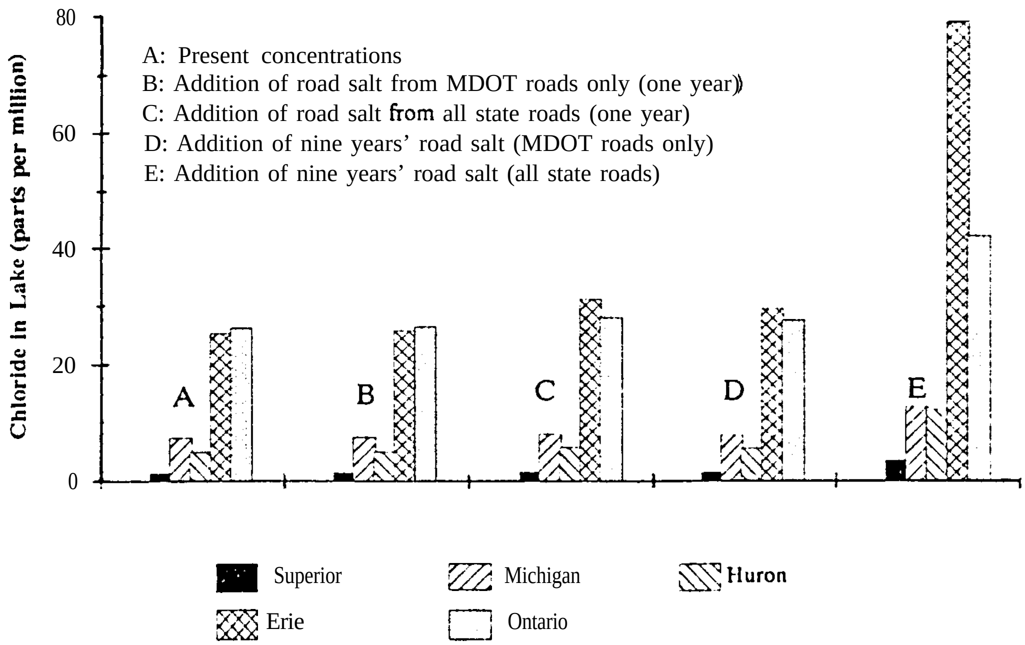
[a] Turnover time. Maximum system turnover time is 200 years.

percent increase in road salt use), after 200 years chloride levels would reach steady state at 60 ppm for Lake Ontario, 50 ppm for Lake Erie, 40 ppm for Lake Michigan, 20 ppm for Lake Huron, and 7.5 ppm for Lake Superior.

Exhibit 4.13 compares current chloride levels in each Great Lake (see column A) to projected levels at four loading levels. The first projects the expected impact of depositing directly into each lake all road salt used for one year on roads under MDOT jurisdiction. It is assumed for this purpose that all the road salt would reach a lake and that channeling effects between the lakes would not occur. The base-line amount of road salt is the average of the last nine years' MDOT road salt usage. The results of this analysis are represented as column B in the exhibit. Comparing columns A and B shows that the addition directly into each lake of an entire year's MDOT road salt usage will not affect its total chloride concentration.

The second analysis projects the effect of directly depositing into each lake all road salt used by the entire state of Michigan for one year (see column C). The estimated total amount of road salt used in Michigan is derived by averaging that used for roadways under the jurisdiction of the MDOT and multiplying that figure by the number of remaining roadways in the state. The estimate is very high

Exhibit 4.13: Impact on Great Lakes' Chloride Levels of Single Direct Addition of One and Nine Years' Use of Road Salt from the MDOT and All Michigan Roads



SOURCE: Public Sector Consultants, Inc.

and, because rural areas do not salt their roads to the extent that the MDOT does, represents a worst-case scenario.

The third analysis projects the effect of depositing nine times the current annual road salt use of the MDOT into each lake (see column D). The fourth projects the increase in chloride levels if nine times the current annual usage of road salt for the entire state of Michigan is dumped directly into each (see column E).

What is surprising about the findings of this model is that chloride concentrations for each lake do not change significantly when road salt is deposited directly into it, not accounting for the channeling effects between lakes, even when nine times the current annual rate of MDOT road salt usage is applied. Increases can be seen when nine times the annual rate of road salt usage for the entire state is directly deposited into each lake; because of its relatively small volume, Lake Erie shows the most dramatic increase.

Comparing these predicted chloride levels to the levels toxic to aquatic biota indicate that *aquatic species in the Great Lakes will not be threatened by current rates of road salt usage.* In addition, the human taste threshold for chloride is 250 ppm, and the projected levels—even in the worst case scenario (E)—do not reach this level. These analyses strongly indicate that current road salt usage will not significantly impact the Great Lakes and that attention should focus on more vulnerable environments.

Vulnerable Environments in Michigan, by MDOT District

For each MDOT district several geographic information system (GIS) maps have been produced that reveal certain geographic, environmental, and demographic features of the district. For each district a transparent overlay also has been produced that shows the district's roadways; this can be laid over the GIS maps. To further assist in identifying areas potentially vulnerable to the effects of deicing materials, additional overlays were made from the GIS maps that show natural resources of specific vulnerability-aquifers; salt-sensitive forest types; and lakes, wetlands, rivers, and streams. This allows users to lay more than one transparency on a map to study areas of compound interest. For example, one can place both the state trunk line and vulnerable aquifer transparencies on a GIS population map to see where high-traffic roads lie adjacent to vulnerable aquifers; this reveals to the user where there is the potential for contaminating groundwater with roadway deicer runoff.

The maps are produced at one'kilometer resolution (that is, the smallest parcel size characterized is one kilometer), using the raster-based Earth Resource Data Analysis geographic information system at the Entomology Spatial Analysis Laboratory of Michigan State University. Because of the maps' one-kilometer resolution, there are limitations to the use of the data in identifying specific sites. For example, if a small lake (.33 kilometer in size) lies in a larger deciduous forest (.66 kilometer in size), the parcel shows on the map as deciduous forest, and the small lake is not represented at all.

This technology, while extremely useful, is expensive. Therefore, only a few sets of the maps and overlays have been made, and they can be found in a sleeve inside the back cover of a limited number of copies of this report. Although they are not included in the copies made for general distribution, readers interested in seeing the maps and overlays may contact the MDOT.

Land Use

For each MDOT district there is a GIS map that shows land uses-urban and developed areas, agricultural areas, range land, deciduous and coniferous forests, inland waters, forested and nonforested wetlands, and barren land. The use to which land is put determines to some extent the impact on the area from road salt usage. For example, salt-sensitive vegetation along urban roadways can be more significantly impacted than that along open highways because of the close proximity to the road, the larger volume of traffic on urban roads, and the high volume of deicing materials used in urban areas.

An additional analysis identifies the land uses in lower peninsula highway corridors, that is, the land within 0.5 kilometer of each side of the roadway. (At the time of the analysis, not all the information was available for the Upper Peninsula.) Exhibit 4.14 indicates that lower peninsula highway corridors, on average, are 57 percent agricultural land, 23 percent deciduous forest, 7 percent forested wetlands, 5 percent coniferous forest, 4 percent urban and developed areas, and 2 percent inland waters; nonforested wetlands, range land, and barren land each comprise less than one percent. The percentage of land uses adjacent to roads sustaining varying rates of traffic also is shown. In general, the analysis shows that the higher the traffic volume, the more likely it is that corridor land is put to agricultural and urban uses and the less likely it is that corridors contain coniferous and deciduous forests.

Exhibit 4.14: Average Trunk Line Corridor Land Use, Lower Penninsula

	Acres	Percentage	Description
	205,598	4.03	Urban and built-up
	2,927,059	57.3 l	Agriculture
	25,946	0.51	Range land
	1,199,983	23.49	Deciduous forest
	257,245	5.04	Coniferous forest
	95,138	1.86	Inland waters
	360,044	7.05	Forested wetlands
	26,935	0.53	Nonforested wetlands
	9,884	0.19	Barren
TOTAL	5,107,836		
	Roads <2,000 Vehicles/Day		
	5,436	0.58	Urban and built-up
	405.513	43.04	Agriculture
	12.108	1.29	Range land
	301,972	32.05	Deciduous forest
	110.953	11.78	Coniferous forest
	25,946	2.75	Inland waters
	71,662	7.61	Forested wetlands
	5,683	0.60	Nonforested wetlands
	2,965	0.31	Barren
TOTAL	942,243		
	Roads 2,000–5,000 Vehicles/Day		
	30.642	1.43	Urban and built-up
	1,211,103	56.67	Agriculture
	9,143	0.43	Range land
	558,970	26.15	Deciduous forest
	105,764	4.95	Coniferous forest
	39,785	1.86	Inland waters
	170,508	7.98	Forested wetlands
	7,907	0.37	Nonforested wetlands
	3,459	0.16	Barren
TOTAL	2,137,284		
	Roads 5,000–10,000 Vehicles/Day		
	54,612	3.62	Urban and built-up
	905.918	60.13	Agriculture
	6,177	0.41	Range land
	3 17,540	21.08	Deciduous forest
	65.237	4.33	Coniferous forest
	34,348	2.28	Inland waters
	108,729	7.22	Forested wetlands
	12.849	0.85	Nonforested wetlands
	1,235	0.08	Barren
TOTAL	1.506.65 1		
	Roads > 10,000 Vehicles/Day		
	145,302	10.36	Urban and built-up
	943,726	67.30	Agriculture
	988	0.07	Range land
	307.08 1	14.77	Deciduous forest
	18,780	1.34	Coniferous forest
	14,579	1.04	Inland waters
	64,990	4.63	Forested wetlands
	4,448	0.32	Nonforested wetlands
	2.47 1	0.18	Barren
TOTAL	1,402,369		

SOURCE: Public Sector Consultants, Inc.

Agriculture comprises the highest percentage of road corridor use in Michigan. No documentation was found in the literature that directly ascribes any adverse impacts of deicing materials on agricultural land. Studies indicate that plants 50 feet or more from the roadside generally are not significantly impacted by deicer spray/splash or root uptake. Generally, agricultural products are grown at distances greater than 50 feet from a roadside. Deicers, such as road salt, that are sprayed/splashed onto soil adjacent to the roadside quickly are diluted by rain or snow melt. Although excessive road salt infiltration can lead to deterioration of soil structure when sodium replaces calcium in the soil, the light-textured soils suitable for farming and pasture have little infiltration when frozen. As a result, much of the road salt is removed by water flow during spring thaw. Damage to crops may occur in extreme cases where (1) drainage from a sloped or banked highway pours directly onto the crops, (2) there is excessive road salt spray/splash, or (3) the soil's sodium level already is high.

Deciduous forests are present in the second highest percentage of highway corridors. In forested areas the salt sensitivities of various dominant tree species in each forest type must be considered. Red/sugar maples and red/pin oaks have been identified as having low tolerance to salt. Tolerance levels of various species are listed in appendix B.

Forest Types

For each district there is a GIS map showing the forest types by dominant species-oak/hickory, maple/yellow birch, aspen/white birch, elm/ash/cottonwood, spruce/fir, and white/red/jack pine. The state trunk line overlay can be used with the forest-type GIS map to identify the location of sensitive tree species.

Forest types in lower peninsula roadway corridors also are analyzed (see Exhibit 4.15). Of the total lower peninsula corridor land, oak/hickory forests occupy 10 percent; aspen/birch, 8 percent; maple/birch, 6 percent; white/red/jack pine, 5 percent; elm/ash/cottonwood, 4 percent; and spruce/fir, 3 percent. This information is further broken down to reveal the percentage of forest types adjacent to roads sustaining varying rates of traffic.

The most significant relationship apparent from the data is that the higher the traffic volume, the lower the amount of forested land. Where there are forested corridors along urban, high-volume roadways. the corridors contain fewer maple/birch, aspen/birch, and white/red/jack pine than do corridors in rural areas. Oak/hickory is the only forest type that seems to maintain a constant percentage—approximately 9-10 percent-in forested corridors adjacent to roadways of any level of traffic.

The species salt-sensitivity list (appendix B) indicates that the forest type most vulnerable to road salt is the white/red/jack pine because white and red pines have low salt tolerance. Other salt-sensitive forest types are maple/yellow birch (red and sugar maples have low tolerance); spruce/fir (balsam fir is susceptible to salt damage); and oak/hickory (red and pin oaks are salt sensitive). It should be reiterated that the forests themselves are not threatened by road salt or other deicers, but individual trees that are salt-sensitive can suffer damage when located near a heavily used roadway. Maps have been created for forest types identified as containing dominant species sensitive to road salt and other

Exhibit 4.15: Average Trunk Line Corridor Forest Types, Lower Peninsula

	Acres	Percentage	Description
	499,169	9.77	Oak/Hickory
	309.633	6.06	Maple/Birch
	39 1,674	7.67	Aspen/Birch
	200,903	3.93	Elm/Ash/Cottonwood
	173,720	3.40	Spruce/Fir
	242,171	4.74	White/Red/Jack Pine
	3,195,424	62.56	Nonforested land
	95,138	1.86	Inland waters
TOTAL	5,107,836		
		Roads < 2,000 Vehicles/Day	
	80.3 11	8.52	Oak/Hickory
	105,764	11.22	Maple/Birch
	101,316	10.75	Aspen/Birch
	35.090	3.72	Elm/Ash/Cottonwood
	60.542	6.43	Spruce/Fir
	101,563	10.78	White/Red/Jack Pine
	43 1,707	45.82	Nonforested land
	25.946	2.75	Inland waters
TOTAL	942,243		
		Roads 2,000–5,000 Vehicles/Day	
	23 1.545	10.83	Oak/Hickory
	143.820	6.73	Maple/Birch
	183,605	8.59	Aspen/Birch
	87,478	4.09	Elm/Ash/Cottonwood
	85,501	4.00	Spruce/Fir
	103,293	4.83	White/Red/Jack Pine
	1,262,255	59.06	Nonforested land
	39,785	1.86	Inland waters
TOTAL	2,137,284		
		Roads 5,000–10,000 Vehicles/Day	
	142,337	9.45	Oak/Hickory
	78,087	5.18	Maple/Birch
	107.247	7.12	Aspen/Birch
	49.916	3.31	Elm/Ash/Cottonwood
	51,893	3.44	Spruce/Fir
	62.025	4.12	White/Red/Jack Pine
	980.793	65.10	Nonforested land
	34.348	2.28	Inland waters
TOTAL	1,506,651		
		Roads > 10,000 Vehicles/Day	
	130.228	9.29	Oak/Hickory
	30,394	2.17	Maple/Birch
	50.658	3.61	Aspen/Birch
	57,577	4.11	Elm/Ash/Cottonwood
	5.436	0.39	Spruce/Fir
	16,556	1.18	White/Red/Jack Pine
	1,096.936	78.22	Nonforested land
	14,579	1.04	Inland waters
TOTAL	1.402.369		

SOURCE: Public Sector Consultants. Inc.

salt compounds. The other forest types are less sensitive to salt, but individual trees may show stress when exposed to the large amounts of road salt commonly used in urban areas.

/n/and Wafers and Wetlands

A GIS map has been prepared for each MDOT district that shows its inland waters, forested wetlands, and nonforested wetlands. Using the state trunk line overlay will show which inland water bodies are adjacent to or intersect state roadways. These areas are not necessarily vulnerable to contamination, but small, low-flow water bodies and wetlands that receive significant roadway runoff can be negatively impacted by deicing materials. These maps include all inland waters and wetlands. If one is interested in learning which water bodies have a low turnover rate or low flow, it will be necessary to conduct a field survey.

Further detail of inland waters, including rivers and streams, are shown on maps produced by the MDNR Resource Information System for each MDOT district.

Deicing materials can significantly impact susceptible water bodies and aquatic biota in three ways: density stratification leading to anoxia, increases in biochemical oxygen demand and associated oxygen depletion; and toxic levels of deicing material components. Density stratification occurs in lakes when the inflowing water is more dense than the normal lake water, due to high concentrations of dissolved salts. The denser, inflowing water sinks to the bottom and can prevent normal spring and fall lake overturn. Without overturn, dissolved oxygen levels in the lake near the bottom are depleted, and organisms dependent on dissolved oxygen in this portion of the lake are eliminated. Lakes most susceptible to this phenomenon are small, relatively deep lakes with closed basins that receive large quantities of deicing material runoff. Few cases of density stratification leading to failure to overturn have been reported in Michigan.

Biochemical oxygen demand can increase when organic compounds enter an aquatic ecosystem and consume oxygen as they degrade. As the supply of dissolved oxygen is depleted, oxygen-dependent aquatic biota are threatened. Acetate is the only deicing compound with potential to increase BOD in inland waters. Water bodies most vulnerable to BOD increases are shallow lakes, ponds, and wetlands with little flushing ability that receive direct runoff from roadways. Studies find severe oxygen depletion in ponds with concentrations greater than 50 ppm CMA.[25]

Chloride, the largest component of many deicing materials, appears to pose the greatest threat of reaching levels toxic to aquatic organisms. Chloride is a conservative element, and it moves along water pathways to surface water. As mentioned, with few exceptions levels of chloride toxic to aquatic organisms that inhabit Michigan water bodies range from 1,000 to 24,300 ppm. Due to dilution, biota in large, flowing water bodies generally are not threatened by these levels of chloride. Most susceptible are aquatic biota in small lakes and streams directly receiving large quantities of runoff, such as those at the discharge points of roadway drainage channels.

There is little documentation on the effects of road salt on wetlands. As mentioned in chapter 3, one study indicates that road salt contamination usually will not change the predominant wetland plant type, although shifts in species within the type may occur. This species shift is a concern when threatened and endangered species are components of the changing communities. Skoog and Pitz recommend using wetlands adjacent to roadways as filtering systems when they have adequate flow and contain tolerant plant species.[26] Exhibit 4.16 indicates the percentage of wetland area and the total wetland acreage in each county of Michigan.

Aquifers

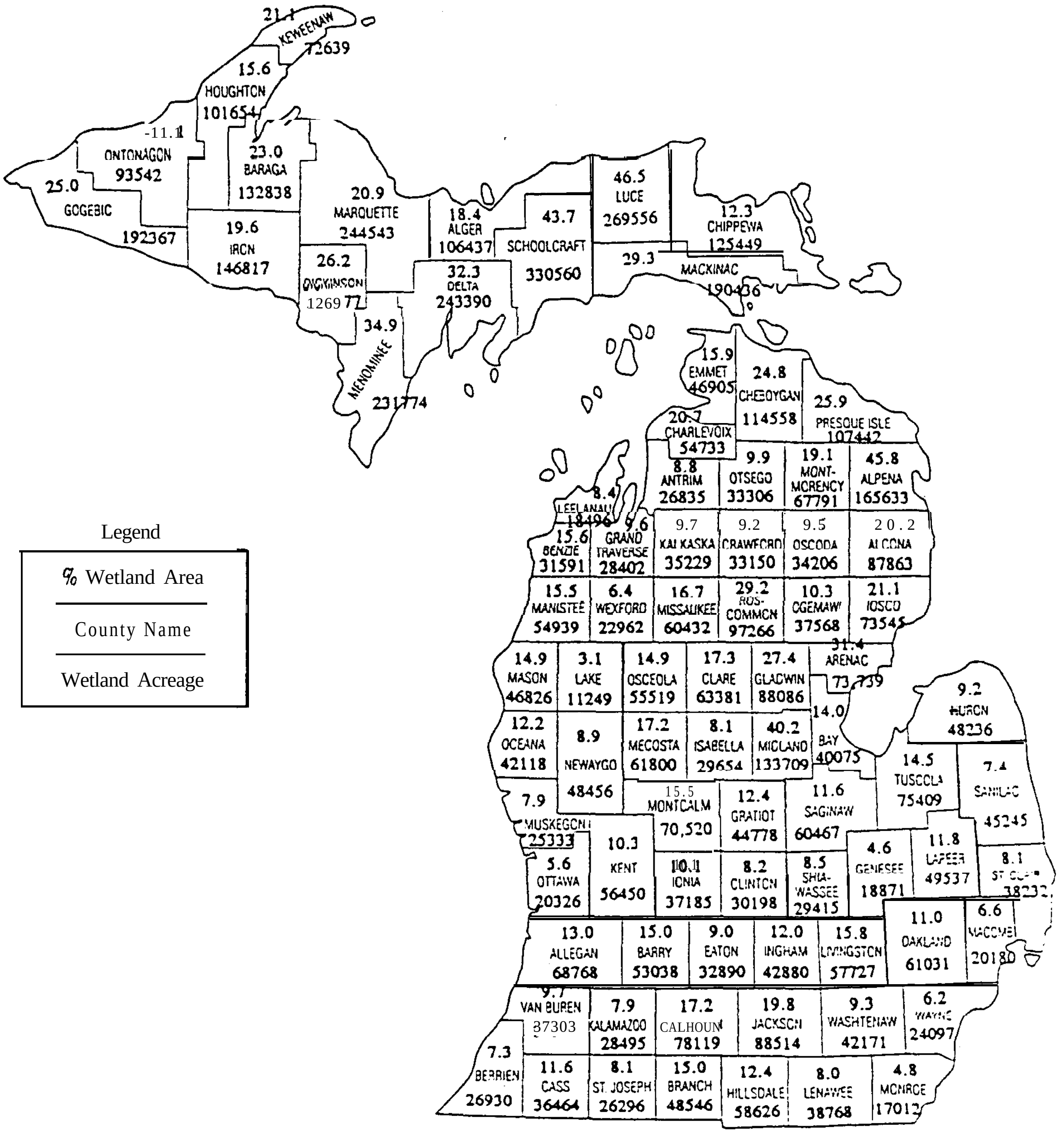
A GIS map identifying vulnerable aquifers has been produced for each MDOT district. In addition, a special state map has been included that identifies in considerable detail the susceptibility to contamination of every aquifer in Michigan. This map, entitled Aquifer Vulnerability to Surface Contamination in Michigan, was prepared by the Center for Remote Sensing and the Department of Geography at Michigan State University. (Because of its size it has not been reproduced for copies of this report made for general circulation.) The vulnerability of an aquifer is characterized by several factors that warrant explanation.

Major aquifers in Michigan are composed of either unconsolidated material deposited by glaciers or consolidated bedrock of ancient geologic formations. Glacial deposits range from highly permeable sand and gravel to relatively impermeable lake clay and till. Bedrock deposits include permeable and impermeable sedimentary units such as sandstone and shale, respectively. Groundwater also collects in fractures of carbonate rocks (e.g., those composed of limestone and dolomite). Carbonate rock is more soluble (easily dissolved) than sandstone or shale. Other Michigan aquifers are composed of igneous and metamorphic rock; water in these relatively insoluble crystalline rocks collects in fractures. Igneous and metamorphic bedrock aquifers are found in the western portion of the Upper Peninsula, while sedimentary bedrock units are found in the eastern Upper Peninsula and the lower peninsula. Glacial aquifers are present throughout the state and are the most often used as domestic water supplies.

The following descriptions are used on the map, and they are defined below to aid users in interpreting the map's depiction of aquifer vulnerability.

- *Highly permeable soils over highly sensitive drift lithology:* This typically is the case where sandy soil is located over sandy drift. Contaminants can easily enter the aquifer system in such areas. Many wells in Michigan tap into such aquifers.
- *Slowly permeable soils:* This indicates the presence of relatively impermeable material, such as soil having a significant percentage of clay. Such soils can protect underlying aquifers from contamination.
- *Less sensitive drift Zithology:* This indicates relatively impermeable glacial deposits. Such material can protect underlying bedrock aquifers from contamination. Few wells in Michigan tap this type of aquifer because the quantity of water is small and frequently impotable.
- *Easily soluble bedrock aquifers:* Usable groundwater in these aquifers lies in limestone and dolomite. Because of such bedrock's soluble nature, contamination can alter these

Exhibit 4.16: Michigan Wetlands, Percentage of Total Area and Acreage Per County



SOURCE: Public Sector Consultants, Inc.

aquifers. For example, increased chloride concentration in groundwater tends to enhance dissolution of the aquifer, which alters groundwater chemistry.

- *Nonsoluble bedrock aquifers:* Sandstone, igneous, and metamorphic rock comprise this group. Groundwater in such aquifers is an important source of potable water in various areas of the state. For example, this is the major source for water in the greater Lansing area.[26]

The vulnerability of aquifers to contamination from deicing materials also depends on their distance from the point of application and the rate of groundwater flow, the topography of land, soil thickness and permeability, depth to groundwater, and groundwater gradient and direction.

As indicated earlier, at one time the major source of deicing contamination of groundwater was spillage and uncontrolled runoff from road salt storage and handling areas, but MDOT facilities have been reconstructed to correct this problem. Most MDOT road salt is stored and loaded in contained facilities, and the department is working toward full containment and effluent restriction.

As described in chapter 3 in the discussion of the effects of road salt on groundwater, tests conducted by the MDOT from 197 1 to 1984 indicate that at that time chloride levels in groundwater throughout the state were within an acceptable range. Extensive monitoring of groundwater by the Michigan Department of Public Health in 1986 indicated that sodium levels in groundwater varied considerably throughout the state due to natural and anthropogenic factors, making it difficult to attribute sodium levels to road salting. There is concern that sodium levels in groundwater can elevate during surge periods accompanying spring thaws, which can affect hypertensive individuals who use groundwater for domestic purposes.

Endangered and Threatened Species

Information from the Michigan Natural Features Inventory by the MDNR Wildlife Division is used to identify endangered and threatened species by county, within each MDOT district. Exhibit 4.17 shows the total number of endangered and threatened species for each county, a breakdown of species habitat-aquatic/lowland or terrestrial/upland, and a *relative sensitivity index.* The sensitivity index is derived by totaling the number of endangered and threatened species, dividing that number by the county square mileage, then multiplying that result by 1,000. Based on the range of sensitivity indices, a scale of five rankings is used: low, moderately low, moderate, moderately high, and high. The index provides a way to identify counties having a high number of endangered and threatened species relative to the rest of the state. Exhibit 4.18 identifies the total number of endangered and threatened species by county as well as the sensitivity index for each county.

Counties showing moderately high to high indices should be further evaluated to identify specific locations of concern; they are Mackinac, Charlevoix, Leelanau, Benzie, Emmet, Cheboygan, Alpena, Muskegon, Ottawa, Kent, Ionia, Allegan, Barry, Van Buren, Kalamazoo, Berrien, Cass, St. Joseph, Livingston, Jackson, Washtenaw, Lenawee, Monroe, Oakland, Macomb, St. Clair, and Wayne. Michigan Resource Information System (MIRIS) maps identifying the specific locations for each of the endangered and threatened species are available from the MDNR.

Exhibit 4.17: Endangered and Threatened Species, by MDOT District, County, and Habitat

	Element Status			Habitat Association									Flora		Fauna		
	E	T	TOT.	L	W	R	A	F	CF	DF	D	U	E	T	E	T	SI
District 1																	
Gogebic	1	12	13	3	5	0	8	2	0	3	0	5	0	9	1	3	12
Ontonngon	1	8	9	2	3	0	5	0	0	4	0	4	1	6	0	2	7
Houghton	0	11	11	3	2	0	5	2	1	3	0	6	0	6	0	5	11
Iron	0	7	7	2	3	0	5	1	1	0	0	2	0	2	0	5	6
Baraga	0	6	6	3	3	0	6	0	0	0	0	0	0	2	0	4	7
Marquette	7	30	37	4	15	1	20	4	2	10	1	17	4	26	3	4	20
Dickinson	1	9	10	2	4	0	6	1	0	3	0	4	1	5	0	4	13
Menominee	3	13	16	2	5	0	7	5	0	4	0	9	1	12	2	1	15
District 2																	
Delta	3	26	29	5	8	0	13	7	3	5	1	16	2	18	1	8	25
Alger	3	14	17	4	4	0	8	3	3	1	2	9	0	10	3	4	9
Schoolcraft	6	27	33	5	15	0	20	8	2	3	0	13	4	20	2	7	28
Luce	2	16	18	6	6	0	12	4	1	1	0	6	2	10	1	5	20
Mackinac	5	31	36	7	14	0	21	8	1	6	0	15	30	24	2	7	36
Chippewa	7	35	42	8	14	0	22	9	1	0	8	18	3	28	4	7	26
District 3																	
Charlevoix	2	19	21	6	6	0	12	5	1	2	I	9	1	11	1	9	51
Leelanau	3	16	19	4	4	0	8	5	1	4	I	11	1	13	2	3	55
Antrim	0	8	8	3	0	0	3	0	2	2	1	5	0	6	0	2	4
Benzie	3	11	14	3	5	0	8	5	0	0	1	6	2	7	1	4	44
Grand Traverse	2	6	8	3	2	0	5	1	0	1	1	3	0	2	2	4	17
Kalkaska	1	4	5	3	1	0	4	0	1	0	0	1	0	1	1	3	9
Manistee	1	8	9	2	2	0	4	2	0	2	1	5	0	4	1	4	16
Wexford	0	3	3	1	0	0	1	0	0	2	0	2	0	2	0	1	5
Missaukee	1	3	4	3	0	0	3	1	0	0	0	1	0	2	1	1	7
Mason	0	8	8	1	4	0	5	1	0	1	1	3	0	7	0	1	16
Lake	0	4	4	2	1	0	3	1	0	0	0	1	0	1	0	3	7
Osceola	0	2	2	1	1	0	2	0	0	0	0	0	0	0	0	2	3
Clare	0	3	3	2	0	0	2	0	0	1	0	1	0	1	0	2	5

NOTE: Habitat association is based on the dominant habitat type of a species' life cycle, although it may be found in or be dependent on other habitat.

Habitat association codes

A = Aquatic/lowland total	R = River	CF = Coniferous forest
L = Lake	U = Upland/terrestrial total	DF = Deciduous forest
W = Wetland	F = Field	D = Dune

Status codes

E = Endangered species	0--10 = Low	11--20 = Moderately low	>41 = High
T = Threatened species	21--30 = Moderate	31--40 = Moderately high	

Sensitivity index = (Total endangered and threatened species) ÷ (county area, squared) x (1000).

Exhibit 4.17: Endangered and Threatened Species, by MDOT District, County, and Habitat (cont.)

	Element Status			Habitat Association									Flora		Fauna		
	E	T	TOT	L	W	R	A	F	CF	DF	D	U	E	T	E	T	SI
District 4																	
Emmet	5	21	26	6	10	0	16	3	1	5	1	10	1	11	4	10	56
Cheboygan	3	19	22	7	10	1	18	2	0	1	1	4	2	11	1	8	31
Presque Isle	1	16	17	5	7	0	12	3	1	0	0	4	0	12	1	4	26
Otsego	0	6	6	3	0	0	3	2	0	1	0	3	0	3	0	3	11
Montmorency	2	6	8	2	3	0	5	2	1	0	0	3	0	5	2	1	14
Alpena	1	18	19	5	3	1	9	2	2	4	1	9	0	12	1	6	34
Crawford	1	8	9	2	2	0	4	3	1	1	0	5	0	4	1	4	16
Oscoda	1	5	6	2	0	0	2	3	1	0	0	4	0	3	1	2	11
Alcona	2	8	10	3	2	1	6	1	2	0	1	4	1	3	1	5	9
Roscommon	2	6	8	3	3	0	6	1	1	0	0	2	0	2	2	4	15
Ogemaw	2	5	7	2	1	1	4	1	1	1	0	3	1	1	1	4	12
Iosco	2	9	11	3	2	2	7	1	2	0	1	4	0	4	2	5	20
District S																	
Oceana	1	5	6	1	1	0	2	3	0	0	1	4	0	3	1	2	11
Newaygo	2	15	17	3	4	2	9	8	0	0	0	8	0	8	2	7	20
Mecosta	0	5	5	2	1	0	3	1	1	0	0	2	0	2	0	3	9
Isabella	1	1	2	0	2	0	2	0	0	0	0	0	0	1	1	0	4
Muskegon	5	21	26	4	13	0	17	7	0	1	1	9	3	15	2	6	52
Montcalm	2	10	12	1	3	0	4	7	0	1	0	8	0	6	2	4	17
Gratiot	1	8	9	0	6	0	6	2	0	1	0	3	1	7	0	1	16
Ottawa	4	14	18	3	8	1	12	1	1	3	1	6	2	13	2	1	32
Kent	4	30	34	2	15	1	18	12	0	4	0	16	2	30	2	0	40
Ionia	1	19	20	0	9	1	10	5	0	5	0	10	0	19	1	0	35
Clinton	2	6	8	1	5	0	6	1	0	2	0	3	1	6	1	1	16
District 6																	
Gladwin	0	1	I	O	1	0	1	0	0	0	0	0	0	1	0	0	2
Arenac	1	4	5	1	1	I	3	0	1	0	1	2	0	2	1	2	14
Midland	2	2	4	0	2	1	3	1	0	0	0	1	0	2	2	0	8
Bay	3	9	12	3	4	0	7	5	0	0	0	5	1	6	2	3	27
Huron	6	12	18	3	2	3	8	5	1	3	I	10	2	6	4	6	22
Saginaw	6	3	9	2	4	3	9	0	0	0	0	0	1	0	5	3	11
Tuscola	3	8	11	1	3	2	6	0	0	2	0	2	2	2	1	3	14
Sanilac	2	1	3	0	0	2	2	0	0	1	0	1	1	0	1	1	3
Shiawasee	1	2	3	0	0	0	0	2	0	1	0	3	0	2	1	6	6
Genesee	2	1	3	0	3	0	0	0	0	0	0	0	2	1	0	0	5
Lapeer	2	2	4	0	1	0	1	3	0	0	0	3	0	2	2	0	6

NOTE: Habitat association is based on the dominant habitat type of a species' life cycle, although it *may* be found in or be dependent on other habitat.

Habitat association codes

- A = Aquatic/lowland total
- L = Lake
- W = Wetland
- R = River
- U = Upland/terrestrial tod
- F = Field
- CF = Coniferous forest
- DF = Deciduous forest
- D = Dune

Status codes

- E = Endangered species
- T = Threatened species
- 0--10 = Low
- 21--30 = Moderate
- 11--20 = Moderately low
- 31--40 = Moderately high
- >41 = High

Sensitivity index = (Total endangered and threatened species) ÷ (county area. squared) x (1000).

Exhibit 4.17: Endangered and Threatened Species, by MDOT District, County, and Habitat (cont.)

	Element Status			Habitat Association									Flora		Fauna		
	E	T	TOT.	L	W	R	A	F	CF	DF	D	U	E	T	E	T	SI
District 7																	
Allegan	7	36	43	6	20	0	26	13	0	3	1	17	4	26	3	10	52
Barry	4	14	18	2	6	0	8	5	1	4	0	10	0	12	4	2	33
Van Buren	4	36	40	1	22	0	23	12	0	4	1	17	1	34	3	2	66
Kalamazoo	10	54	64	2	28	2	32	24	0	8	0	32	5	51	5	3	114
Calhoun	4	13	17	1	7	1	9	6	0	2	0	8	0	13	4	0	24
Berrien	14	60	74	5	28	2	35	23	0	15	1	39	7	52	7	8	128
Cass	12	40	52	3	17	2	22	22	0	8	0	30	3	39	9	1	106
St. Joseph	8	31	39	0	11	3	14	18	0	7	0	25	3	28	5	3	77
Branch	4	5	9	1	3	1	5	0	0	4	0	4	0	4	4	1	18
District 8																	
Eaton	5	5	10	1	3	0	4	2	0	4	0	6	1	5	4	0	IS
Ingham	1	14	15	0	7	0	7	3	0	5	0	8	1	13	0	1	27
Livingston	5	15	20	0	7	4	11	8	0	1	0	9	0	10	4	5	35
Jackson	4	20	24	1	10	1	12	9	0	3	0	12	1	17	3	3	34
Washtenaw	15	40	55	0	26	6	32	18	0	5	0	23	7	34	8	6	77
Hillsdale	5	11	16	1	4	5	10	3	0	3	0	6	0	7	5	4	27
Lenawee	7	23	30	2	5	6	13	12	0	5	0	17	3	17	4	6	40
Monroe	12	32	44	2	11	9	22	14	0	8	0	22	4	22	8	10	79
Metro Detroit																	
Oakland	8	32	40	2	10	5	17	18	0	5	0	23	3	27	5	5	47
Macomb	4	13	17	1	5	3	9	2	0	6	0	8	1	9	3	4	35
St. Clair	10	35	45	4	20	5	29	9	1	6	0	16	6	30	4	5	61
Wayne	9	39	48	1	20	9	30	13	0	5	0	18	3	33	6	6	79

SOURCE: Public Sector Consultants. Inc

NOTE: Habitat association is based on the dominant habitat type of a species' life cycle. although it may be found in or be dependent on other habitat.

Habitat association codes

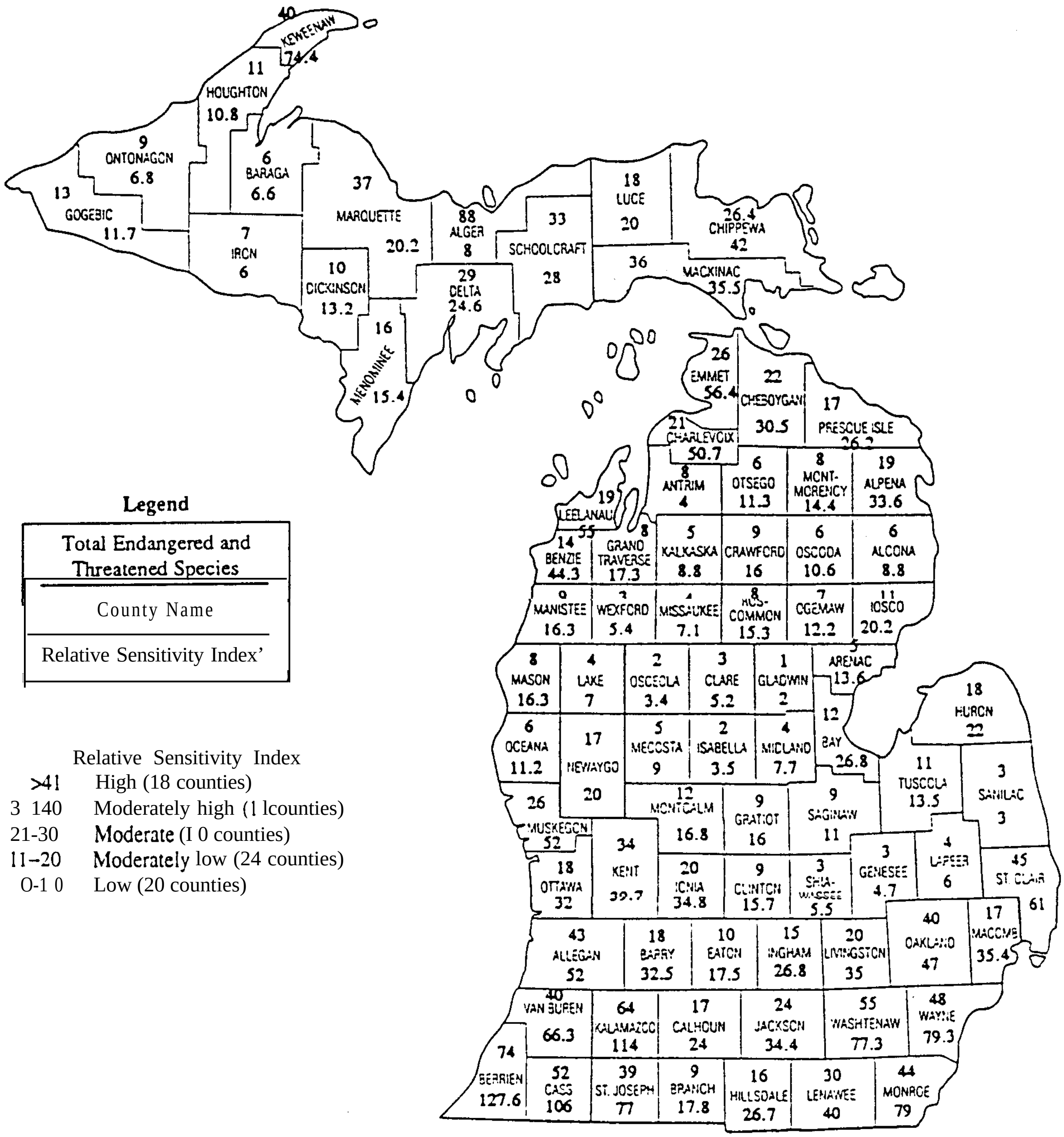
- A = Aquatic/lowland total
- L = Lake
- W = Wetland
- R = River
- U = Upland/terrestrial total
- F = Field
- CF = Coniferous forest
- DF = Deciduous forest
- D = Dune

Status codes

- E = Endangered species
- T = Threatened species
- O--IO = Low
- 21--30 = Moderate
- I l--20 = Moderately low
- 3 1--40 = Moderately high
- >41 = High

Sensitivity index = (Total endangered and threatened species) ÷ (county area, squared) x (1000).

Exhibit 4.18: Total Endangered and Threatened Species by Michigan County, with Indicator of Relative Sensitivity



SOURCE: Public Sector Consultants, Inc.

[1] Index Calculation: Total number of endangered and threatened species ÷ county square milegc x 1,000.

Although Exhibit 4.18 shows significantly higher numbers of threatened and endangered species in the southern regions of the state, it is not clear whether this is indeed the case or whether the higher numbers simply reflect more investigation.

Population Centers

A GIS map showing urban and developed areas has been produced for each MDOT district. Use of the state trunk line overlay will identify specific locales that may be exposed to higher quantities of deicing materials because they are in areas of higher traffic volume. Deicing runoff in urban areas often is concentrated because dispersal is limited by a considerable amount of impermeable pavement. Trees adjacent to roadways in urban areas suffer some damage because they are close to roadways, more deicer is used. and some species have a low tolerance to salt. When replanting corridors, the MDOT should keep in mind that along urban roadways, trees more tolerant of salt will fare much better than other species.

Small lakes in urban areas are vulnerable to density stratification and subsequent anoxic conditions. As mentioned in chapter 3. a small, closed-basin lake near Xnn Arbor received direct runoff from the roadways in a surrounding subdivision and from adjacent two- and four-lane roads. In the 1960s the lake was density stratified and did not overturn during the spring thaw, causing oxygen depletion and the death of oxygen-dependent aquatic biota. The chloride eventually leached out of the lake sediments, and natural overturn occurred in subsequent years.

Summary

As the analysis indicates, there are no widespread environmental effects from the current use of deicing materials. Chloride levels in the Great Lakes remain significantly below levels that affect aquatic biota or human health. Areas susceptible to damage are very site specific, and maps used in conjunction with field surveys are needed to specifically identify vulnerable environments.

NOTES

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